



Setting the Standard for Automation™

Advanced Space Radiation Detector Technology Development

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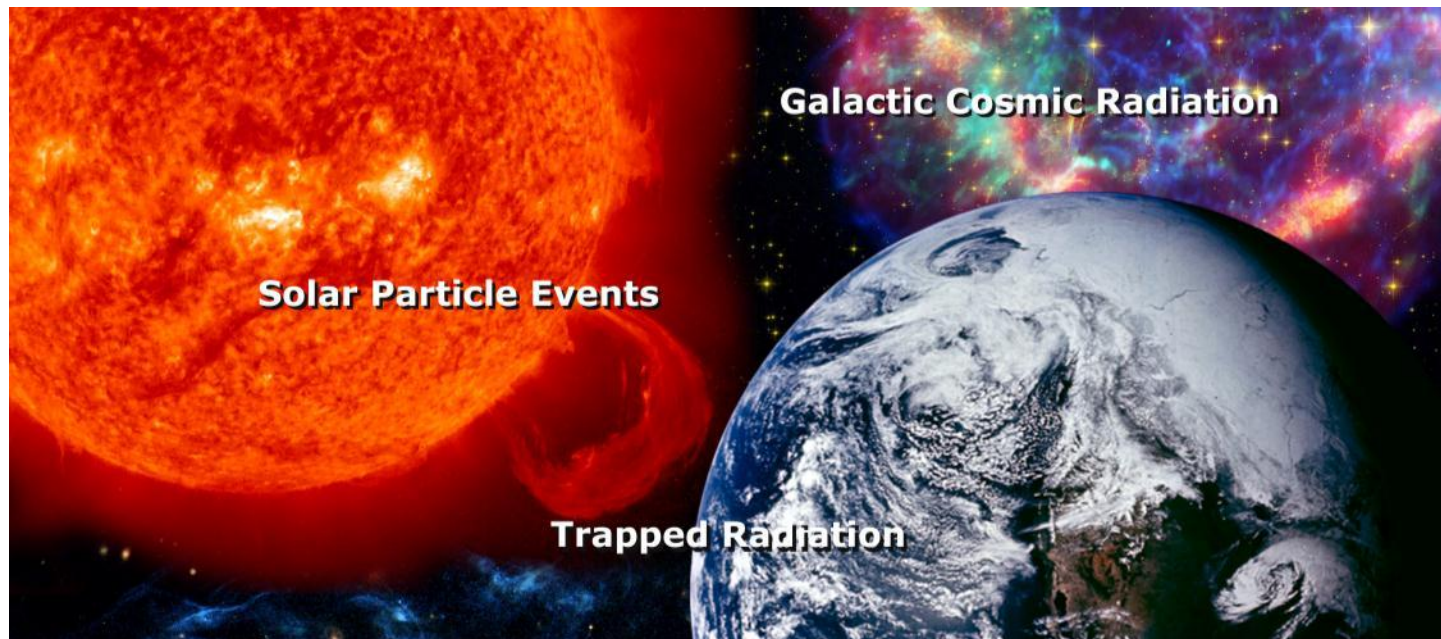


- NASA Glenn Research Center since 2000
 - Physics background
 - Previously at AFRL (plasma physics research & technology) and FNAL (particle beam optical systems)
- Physical Sensors Instrumentation Research @ NASA GRC
 - Micro-fabricated thin-film sensor technology for temperature, strain, heat flux, and radiation measurement for aerospace systems applications
- NASA Support for GRC's Advanced Radiation Detector Technology R&D:
 - AEVA Power, Communications, Avionics, Informatics (2005-2007)
 - ETDP/D Life Support & Habitation Systems/Radiation Protection (2009-2011), AES Radiation Protection (2012)
 - OCT/CIF (2011, 2012)



- Space Radiation Environment
 - Radiation Detector Issues
- GRC Technology Research & Development
- Application Concept System
 - Objectives
 - Design
- Detector Development
 - WBG LET Detectors
 - Fast Solid-State Cherenkov Detector
 - Solid-State UV Detector Investigation
- Technology Challenges
- Summary

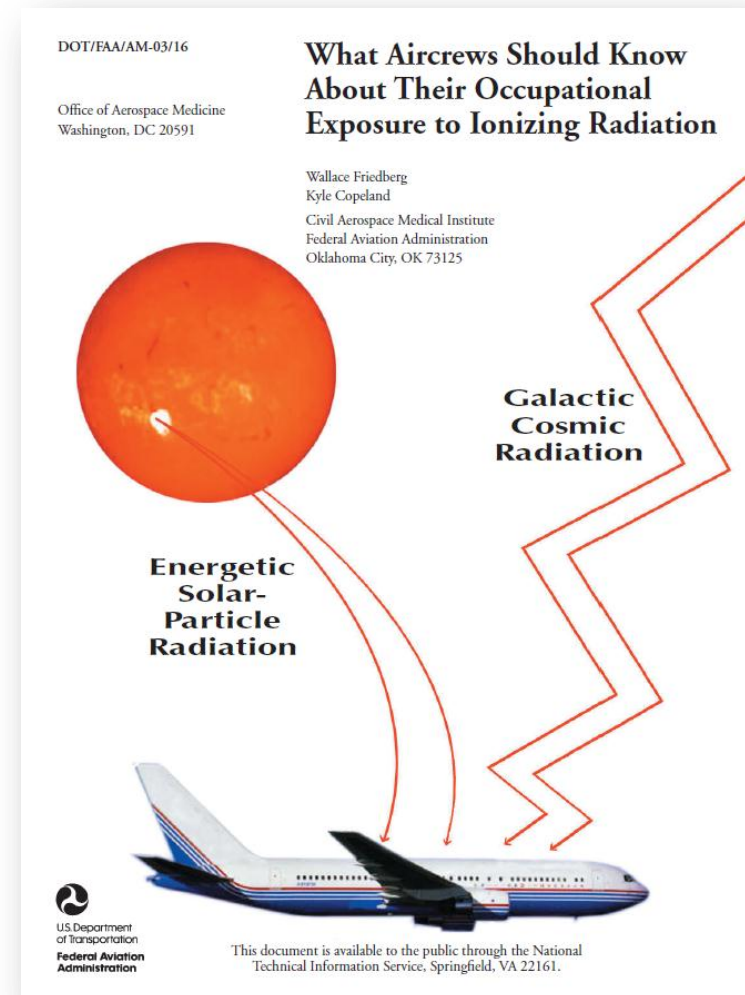
- Types of Radiation from Space:
 - Solar Particle Events (SPE): Mostly protons, some helium ions, at moderate energies
 - Galactic Cosmic Radiation (GCR): Moderate to highly energetic ions, $Z=1 \rightarrow 26$ (Hydrogen to Iron nuclei)
 - Trapped Radiation: Ions and electrons from SPEs, GCR trapped, scattered by the planetary magnetic field



Space Radiation Environment Impact on Air Travel



- Aircrews are considered Radiation Workers by the FAA due to Space Radiation exposure
 - Concern for altitudes over 8 km (26,000 ft)
 - Dose at 18km (60,000 ft) altitude is about 2x dose at 12km (40,000 ft)
 - Polar routes can receive about 3x exposure than equatorial routes
 - Solar Particle Events can increase doses 3x in flight
- Aircrew dose estimate models are dependent on the understanding of the space radiation environment



Space Radiation Environment Impact on Space Exploration

- Space Radiation exposure is more pronounced beyond the protection of Earth's atmosphere and magnetic field
 - SPEs introduce a large variability to radiation dose for equipment and crew
 - Radiation Doses from Trapped Radiation need to be accounted for in traversing magnetic fields
 - Variations in HZE from GCR are not fully understood (do the most damage)

Radiation Area	Average Exposure Rate
Terrestrial (background)	0.25 μ Sv/hr
Aircraft (@ 12 km)	2.7-7.4 μ Sv/hr
LEO (@400 km)	2-16 μ Sv/hr
MEO (@20,000 km)	1 mSv/hr
Deep Space GCR	57 μ Sv/hr
Deep Space SPE	→125 mSv/hr
Europa (Jupiter orbit)	40 Sv/hr



Space Radiation Environment Radiation Detector Issues

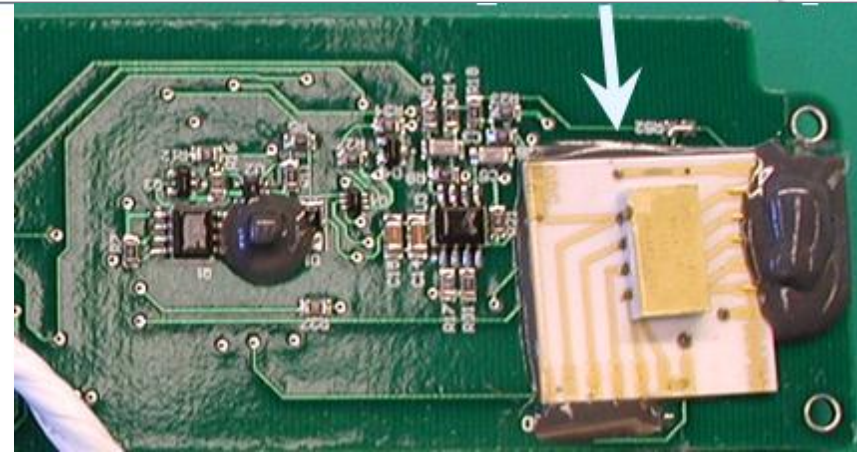


- Existing space radiation data sets have gaps in energy, ion type
- Understanding of variations in steady state and storm conditions are limited
- Current radiation detector technology is limited in lifetime, precision, discrimination, and directional sensitivity by the mass, power, and volume requirements for future missions
- Limitations of knowledge of the radiation environment impact:
 - Space Science/Exploration: Spacecraft design and operation
 - Earth Science: Heavy ion mechanisms in large-scale cloud cover
 - Aeronautics: Aircraft crew rotations on intercontinental flights

GRC Advanced Radiation Detector Technology Research and Development



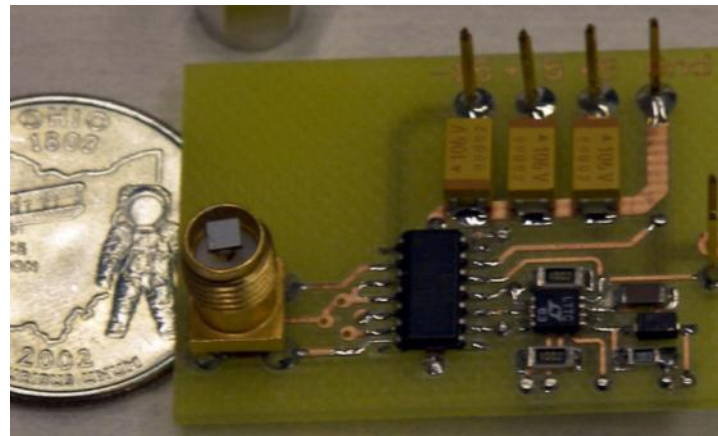
- GRC Expertise and Facilities in:
 - Harsh Environment Thin Films
 - SiC Devices & Harsh Environment Packaging
 - Micro-Optics
 - Space-Based Instrumentation
- These strengths are combined into an in-house Radiation Instrumentation Research effort



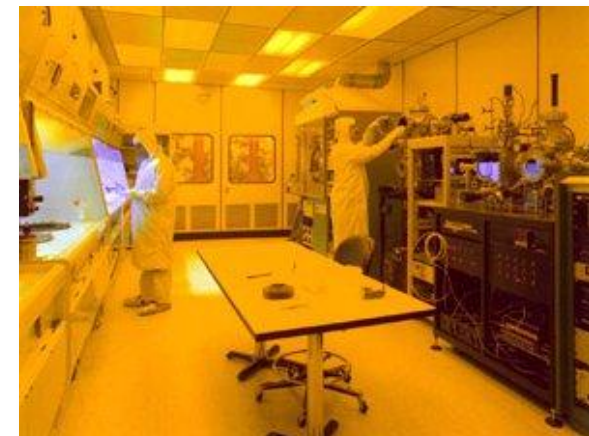
MISSE 7 SiC JFET & Ceramic Packaging (arrow) on a Rad-Hard Electronics Board



SiC radiation detector for AEVA PCAI studies



Dosimeter based on SiC diode detector element for Constellation ETPD demonstration



In-House Microfabrication Facilities

Application Concept: Full-Field Radiation Detector System



- GRC is advancing the technology to develop a low-power radiation detector system capable of monitoring a wide range of high energy heavy ions (HZE ions) over a spherical (4π) aspect area
- The technology applied to this 4π HZE Detector System enables:
 - Improved temperature insensitivity to changes induced by transitions from sunlight into shadow (and vise-versa)
 - Improved precision with lower mass, power and volume requirements
 - Improved radiation discrimination and directional sensitivity
 - Unique monitoring of radiation environment from all directions of the celestial sphere

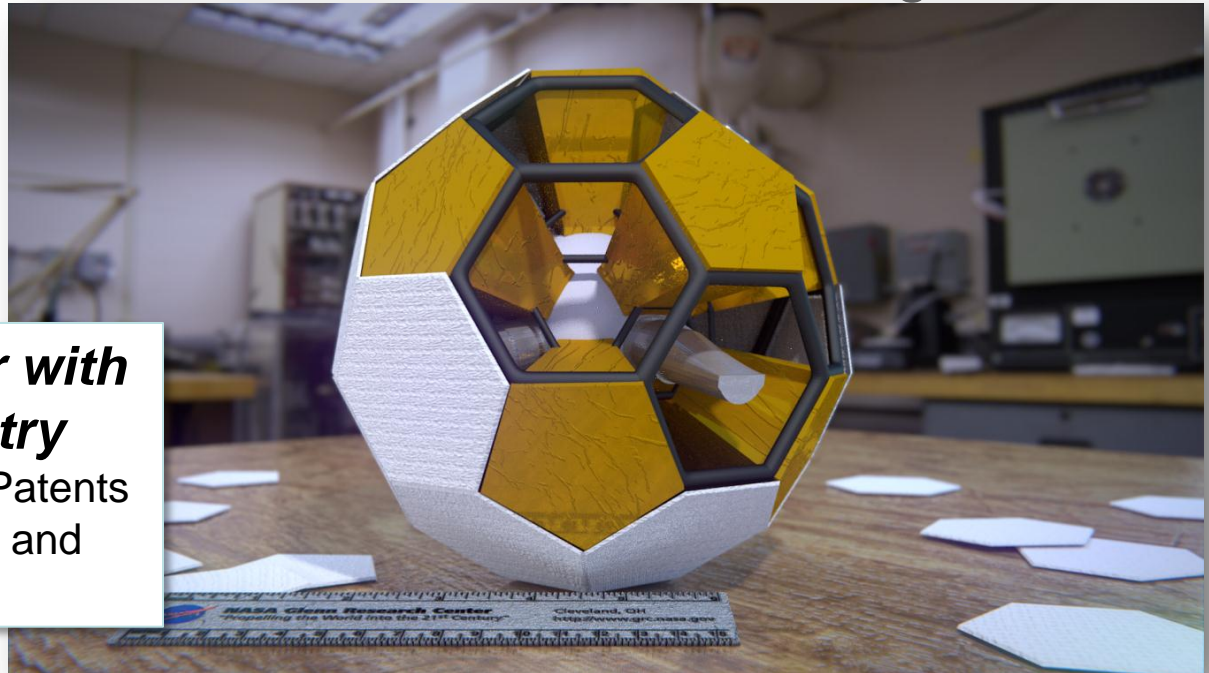
Application Concept: Full-Field Radiation Detector System



- Mapping of heavy ions $> 100 \text{ MeV/amu}$
 - Integrated system with solid-state Cherenkov detector and large area detectors in surrounding wedges
- High radiation flux rates for 10+ year missions
 - Precision rad-hard, thermally stable wide band gap detectors used
- Low noise, multi-directional measurements at single locations
 - Compact, spherical detector system

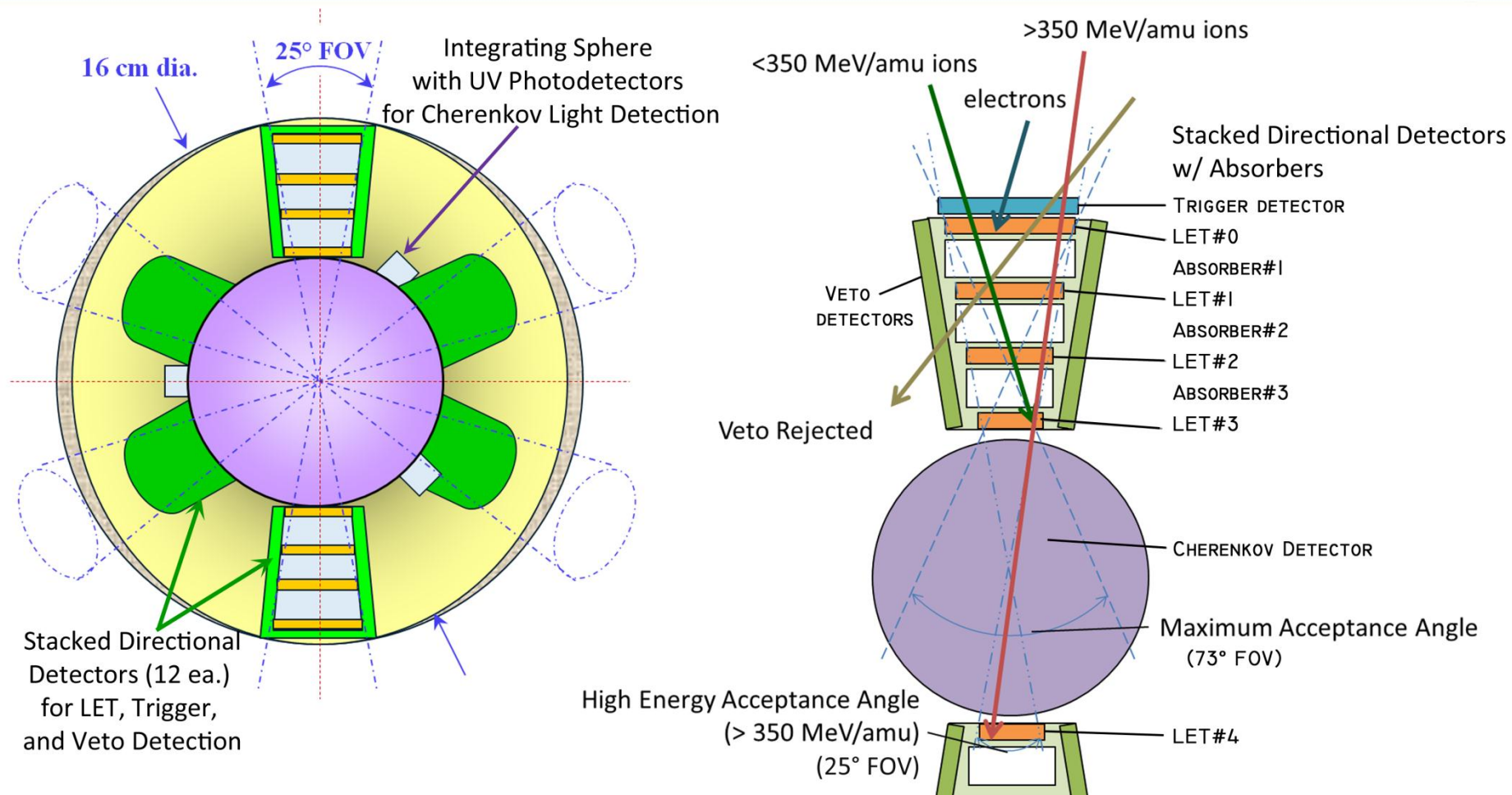
Space radiation detector with spherical geometry

- Technology covered by U.S. Patents 7,872,750 (January 18, 2011) and 8,159,669 (April 17, 2012)



Concept illustration of 4n Space Radiation Detector System (cables and signal conditioning not shown)

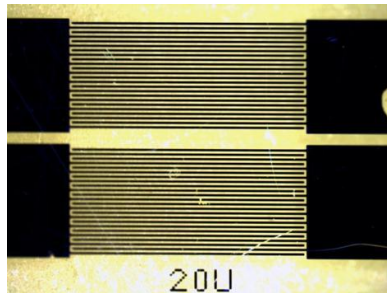
Application Concept: Full-Field Radiation Detector System



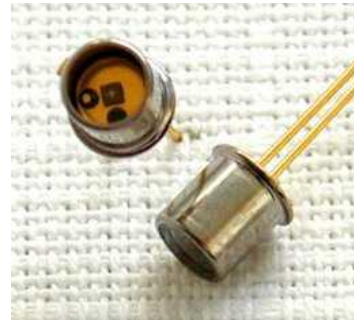
- Full-field ion detector system comprised of a spherical Cherenkov detector surrounded by stacked LET detectors

- Each stack of directional detectors has several Linear Energy Transfer (LET) detectors with layers of absorbers with a separate Trigger detector to initiate data collection
 - LET detectors measure dE/dx as the ion moves through the stack
 - Based on the absorber geometry, the dE/dx signal can be correlated to ion Z and velocity
- The Wide Band Gap (WBG) semiconductor SiC selected for the LET detectors
 - Resistance to radiation damage
 - Insensitivity to changes in temperature
 - Demonstrated performance in the ETDP dosimeter
- Detectors up to 450 mm^2 required – Fabrication Options:
 - Large area array of 4 mm^2 diodes as used in the dosimeter
 - Large area detector from a single-crystal SiC wafer

- With the trigger of data collection from the stacks, the signal from the central Cherenkov detector is collected via fast UV photodetectors
 - The collected Cherenkov light emitted by particles over 200 MeV/amu can be correlated to ion Z and velocity
- Requires solid-state fast UV detectors in place of PMTs
 - Typically photomultiplier tubes (PMTs) are used for their sensitivity and fast response; no room for that in this application
 - Investigated solid-state UV detectors, both COTS & custom



Proof-of-Concept ZnO UV
Detector (GRC, patent pend.)



SG01L-18 SiC UV
Photodiode (©sglux)



FGAP71 GaP UV
Photodiode (©Thorlabs)

- Fabricated a 2 mm² active area ZnO detector and compared to COTS SiC and GaP photodiodes at 254 nm and 370 nm light sources
 - ZnO detector most sensitive at both wavelengths
 - GaP diode better than SiC at 370 nm
 - SiC diode as good as GaP at 254 nm

Diode	ZnO (per Volt bias)	SiC (-10V bias)	GaP (-10V bias)
Detector Area	2 mm ²	0.96 mm ²	4.8 mm ²
Average Dark Current	1.8 ± 0.2 nAmps	< 50 pAmps	100 ± 20 pAmps
Relative Output to Hg lamp (254 nm)	58.7 ± 3.8	0.196 ± 0.029	1
Relative Output to LED source (370 nm)	14.99 ± 5.6	0.041 ± 0.0024	1
Relative Output to Hg lamp (254 nm) per unit area (mm ⁻²)	14.09 ± 0.91	0.981 ± 0.147	1
Relative Output to LED source (370 nm) per unit area (mm ⁻²)	3.6 ± 1.3	0.207 ± 0.012	1

- ZnO detector with 20 μm electrode spacing, low resistance should have a response time of ~ 1 ns
 - Package not developed
- GaP strong response at 370 nm makes it an excellent candidate for use in scintillator trigger/veto counters
- SiC diode can be a backup to the ZnO detector assuming a fast response time can be achieved

Technology Challenges



Component	Technology Challenge	Approach
Fast Cherenkov Detector	ZnO UV detector packaging	GRC Harsh Environment Packaging expertise; Examine SiC diode back-up
Trigger/Veto Scintillator Counters	GaP photodiodes with fiber scintillators	Compare COTS to custom packaging
Large Area WGB LET Detectors	SiC Diode array	GRC Harsh Environment Packaging expertise; Examine single-crystal option
Signal Conditioning Electronics	Space available	GRC Space Electronics expertise
Detector Integration	Mass limit	More reliance on lower density metals (Al, Ti); Higher fidelity models

- Radiation detector issues impact a variety of missions in both air and space
- GRC is leveraging expertise in harsh environment thin films, SiC devices & harsh environment packaging, micro-optics, and space-based instrumentation to advance radiation detector technology
- Application concept system for a compact, full-field space radiation detector system outlined
- Detector development proceeding in WBG devices for LET and Cherenkov detectors
- Technology challenges identified and are being addressed

Acknowledgements



- Elizabeth McQuaid and Nicholas Varaljay (GRC/FTF)
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 - SiC dosimeter diode detector fabrication
- Dr. Jon Freeman (GRC/RHE) and Dr. Stephen P. Berkebille (ORAU)
 - General semiconductor and shielding studies for space radiation protection

